SPATIAL AND TEMPORAL EVOLUTION OF SOFT AND HARD X-RAY EMISSION IN A SOLAR FLARE

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(Received 5 July; in revised form 24 November, 1981)

Abstract. We study the spatial and temporal characteristics of the 3.5 to 30.0 keV emission in a solar flare on April 10, 1980. The data were obtained by the Hard X-ray Imaging Spectrometer aboard the Solar Maximum Mission Satellite. It is complemented in our analysis with data from other instruments on the same spacecraft, in particular that of the Hard X-ray Burst Spectrometer.

Key results of our investigation are: (a) Continuous energy release is needed to sustain the increase of the emission through the rising phase of the flare, before and after the impulsive phase in hard X-rays. The energy release is characterized by the production of hot ($5 \times 10^7 \leq T \leq 1.5 \times 10^8$ K) thermal regions within the flare loop structures. (b) The observational parameters characterizing the impulsive burst show that it is most likely associated with non-thermal processes (particle acceleration). (c) The continuous energy release is associated with strong chromospheric evaporation, as evidenced in the spectral line behavior determined from the Bent Crystal Spectrometer data. Both processes seem to stop just before flare maximum, and the subsequent evolution is most likely governed by the radiative cooling of the flare plasma.

1. Introduction

We present in this paper an analysis of the temporal and spatial development of the 3.5 to 30.0 keV X-ray emission in a solar flare which occurred on 1980 April 10, in active region NOAA 2372.

The X-ray images have been obtained by the Hard X-Ray Imaging Spectrometer (HXIS) aboard the Solar Maximum Mission Satellite (SMM). The instrument capabilities and description have been given by van Beek et al. (1980). For preliminary results and details on the instrument performance we refer the reader to papers by Simnett et al. (1981), van Beek et al. (1981), and Hoyng et al. (1981a, b).

The April 10 event has been classified as M4 in the X-ray scale and as a 1 N flare in Hz. It occurred in the north-western hemisphere at N12 W42. The Hα event was reported starting at $9^h14^m$ UT reaching its maximum at $9^h23^m$ UT. It was accompanied by a microwave burst with a maximum flux of 180 sfu at 8.8 GHz at $9^h21^m$. Hoyng et al. (1981a) have given a preliminary analysis of the HXIS observations and show the spatial distribution of the emission at the time of the impulsive hard X-ray burst.
In Section 2 we give a brief description of the instrument capabilities and operational modes, while in Section 3 to 6 we discuss the flare observations and their interpretation. We also refer in our discussion to complementary data sets obtained by other instruments on board of the SMM, in particular to those obtained by the Hard X-Ray Burst Spectrometer (HXRBS, Orwig et al., 1980), the X-Ray Polychromator (XRP, Acton et al., 1980) and the Ultraviolet Spectrometer and Polarimeter (UVSP, Woodgate et al., 1980).

2. Instrument Capabilities

The Hard X-Ray Imaging Spectrometer (van Beek et al., 1980) is capable of imaging solar flare X-rays in the energy range 3.5 to 30.0 keV. Its spatial resolution is 8″ (FWHM) in its fine field of view which covers an area of 2′40″ by 2′40″ on the Sun, and 32″ in its coarse field of view which sees a larger, 6′24″ by 6′24″ area. Hard X-ray emission in the energy range 16.0 to 30.0 keV is also recorded, without spatial resolution, by the HXIS high energy monitor (HEM) within a 10′ by 10′ (FWHM) area. The temporal resolution varies from 1.5 s to 4.5 s according to the observational mode.

Neighbors pixels of both the coarse and fine fields of view spatially overlap. As a result, a point source will in general cause a response in more than one pixel, unless it is located exactly in the middle of the pixel.

The energy range observed by the HXIS is split up into six energy bands, referred to as band 1 to band 6 (B1 to B6) in the following way, B1: 3.5 to 5.5 keV, B2: 5.5 to 8.0 keV, B3: 8.0 to 11.5 keV, B4: 11.5 to 16.0 keV, B5: 16.0 to 22.0 keV and B6: 22.0 to 30.0 keV.

For further details consult van Beek et al. (1980).

3. Pre-Flare Observations

The HXIS observations started at 8h50m, at the beginning of the satellite day and about 24 min before the start of the X-ray event. Figure 1 (from Hoyng et al., 1981a) shows the time evolution of the X-ray emission as recorded in all six energy bands.

It can be clearly seen in these plots that the emission in the lower energy bands show small amplitude long-lived intensity fluctuations prior to the impulsive burst observed at high energies. The same type of fluctuations were detected by the Bent Crystal Spectrometer (BCS, see reference to XRP) Ca xix data and in the N v transition zone line recorded by the UVSP. A qualitative inspection (see also Section 5) of count ratios in the low energy bands shows that the observed variations are most likely due to temperature fluctuations in the region. Similar results are obtained from Ca xix line ratios which are sensitive to temperature changes (Antonucci, private communication). Examination of the flare region within the HXIS fine field of view shows that the bulk of the emission in these pre-flare brightenings comes from a fairly localized area towards the west of what will subsequently be the main flare region, within and around an area bright in N v which also shows up later during the impulsive phase as a footpoint, in the higher energies (cf. Figure 3 and Section 4).